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Review

Elbow joint biomechanics for preclinical evaluation of total elbow prostheses

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ABSTRACT

Total elbow arthroplasty is a clinically successful procedure, yet long-term implant survival rates have historically lagged behind those reported for total hips and knees. Clinical complications associated with implant wear, osteolysis, stem loosening and device fracture have been implicated as reasons for limited long-term survivorship. Unfortunately, there is little published information on the biomechanics and method(s) for preclinical evaluation of total elbow prostheses that could provide insight into the mechanisms of failure. Additionally, there are no consensus testing standards or summaries of loading profiles of the humero-ulnar joint associated with a range of activities of daily living. Such data would facilitate the standardized preclinical assessment of total elbow devices such is commonplace for other large joints. The objective of the work here is therefore to provide a comprehensive review of elbow joint biomechanics as it relates to preclinical evaluation of total elbow implants. This summary includes a review of elbow joint forces, kinematics, the types and frequency of humero-ulnar joint motions associated with activities of daily living and clinical outcomes, as well as proposing a methodology for deriving humero-ulnar joint reaction force magnitudes and vector orientations as a function of a known mass/force at the hand. From these data, a scalable, bi-axial loading profile is proposed as a foundation for the development of clinically relevant, laboratory simulations for assessment of total elbow prostheses performance.

Contents

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1. Introduction

Total elbow arthroplasty is a clinically successful procedure, yet long-term implant survival rates have historically lagged behind those reported for total hips and knees (Voloshin et al., 2011). Clinical complications associated with implant wear, osteolysis, stem loosening and device fracture have been implicated as reasons for limited long-term survivorship. Unfortunately, there is little published information on the biomechanics and method (s) for preclinical evaluation of total elbow replacements (TER) that could provide insight into the mechanisms of failure. Additionally, there are no consensus testing methods or summaries of loading profiles of the humero-ulnar (HU) joint associated with various activities of daily living (ADL). Such data would facilitate laboratory assessment of total elbow device performance through simulations such is commonplace for other large joints (ASTM F2083-11 , 2011;ISO 7206, , 2011). Consequently, it is hypothesized that advancements in TER device design as reflected in improved clinical survivorship have been impacted by lack of these data. Testing of this hypothesis is not possible without standardized loading profiles by which to benchmark designs in the laboratory and retrospectively correlate to long-term clinical outcomes. The objective of this study is therefore to review and summarize the current state of knowledge on human elbow joint biomechanics and kinematics and to develop a basic set of scalable, bi-axial elbow loading profiles appropriate for use in preclinical assessment of TER. Since most contemporary TERs are HU-only type devices, the focus of this study is the HU joint.

2. Experimental materials and method

The human elbow joint complex includes the distal end of the humerus and the proximal ends of the ulna and radius (Fig. 1) (Day, 2009). The bifurcated distal end of the humerus is formed by the trochlea (medially) and capitellum (laterally) which articulate against the ulna and radius, respectively. These three primary articulations, the humero-ulnar (HU), humero-radial (HR) and proximal radio-ulnar (RU), facilitate two active and

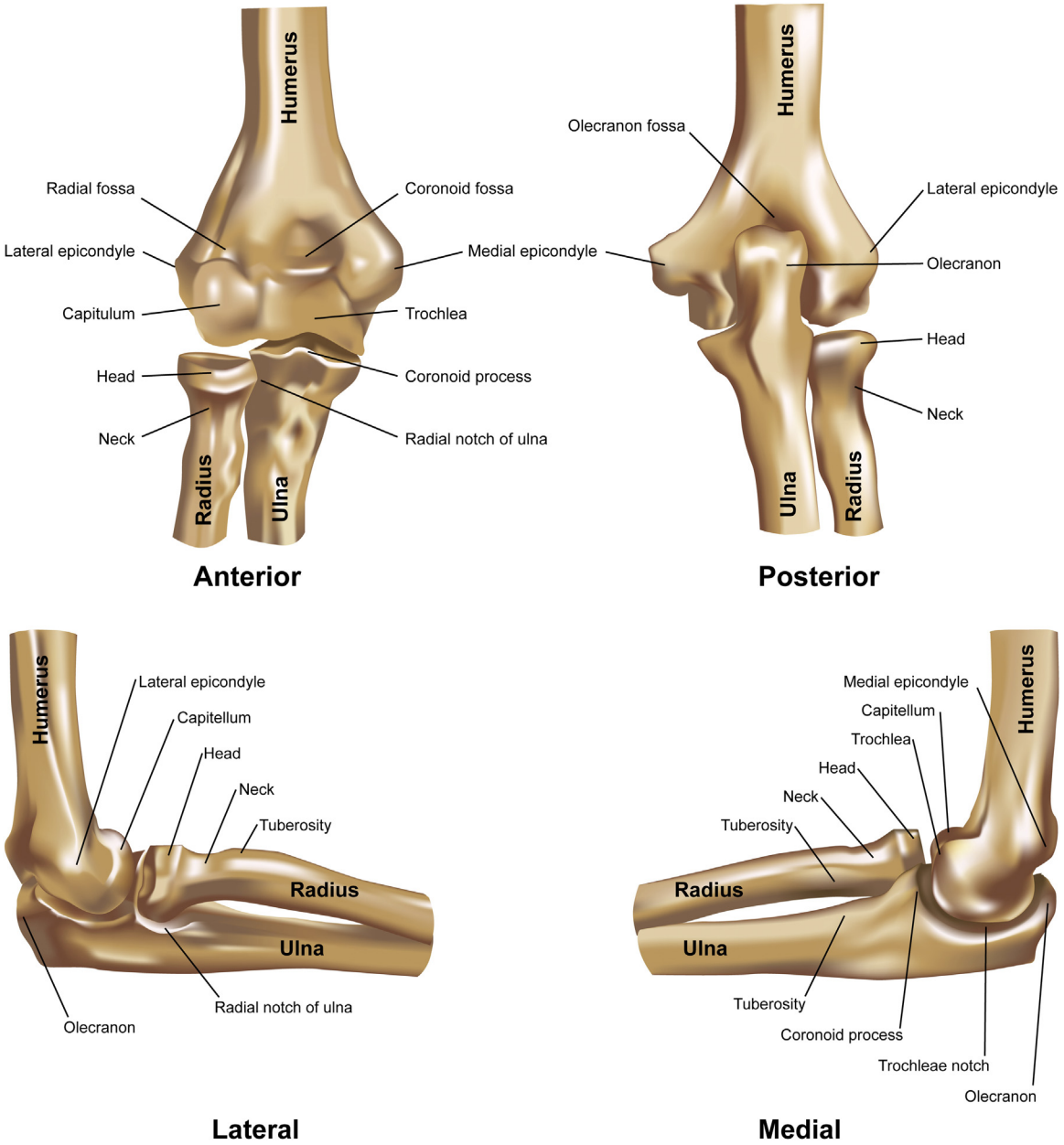

Fig. 1. Osteoarticular Anatomy of the Human Elbow Joint (Reprinted from Day (2009), with permission from Elsevier).

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